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Technical Note 72-2

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HANDBOOK FOR THE CALCULATION OF APPROXIMATE DATA RATES FOR SPACEBORNE SENSORS

August 1972

(NASA-CR-130200) HANDBOOK FOR THE CALCULATION OF APPROXIMATE DATA FOR SPACEBORNE SENSORS (Operations Research, Inc.) ~~54~~ 48 p HC $5.75 CSCL 14B

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Prepared under Contract No. NAS5-21709
for Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland 20771

Operations Research, Inc. A LEASCO Company

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OPERATIONS RESEARCH, Inc.

SILVER SPRING, MARYLAND

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I. INTRODUCTION

As the usefulness of space for earth observations and other scientific purposes increases, the scientific community's demands for new and additional sensing instruments grow. In almost every case, with the exception of short-lived spacecraft which return their data physically to earth, all data taken in space must be transmitted electromagnetically back to earth for processing and analysis.

In allocating the RF spectrum for the transmission of sensed data from space to earth, the characteristics of the data produced by each sensor are of primary importance. For example, data may be in the form of a continually varying voltage (analog) or may be a series of discrete pulses (digital). For the analog signal, its important characteristics to the spectrum allocator are its highest frequency component (bandwidth) and its range from minimum values (dynamic range or signal-to-noise ratio). For the digital signal, the characteristic of interest is the bit rate.

RESOLUTION

Bandwidth is directly related to the number of resolution elements sensed per unit time. There is not a generally accepted definition of resolution element; however, one reasonable approximation to the size of a resolution element is the instantaneous field-of-view. A more accurate determination of resolution element occurs when the "pixel" or picture elements, as defined by the following experiment, is used.

A detector is to complete one scan across a scene in T_{SO} seconds. If the scene is made up of equal width bars alternating in intensity between the level which saturates the detector and the detector minimum sensitivity level, the detector output will be in the form of a square wave, with the

number of cycles equal to the number of high (or low) intensity bars. See Figure 1-1a. As the width of the bars is decreased and their number increased, with the scan time held constant, the square wave starts being rounded and eventually becomes something resembling a sine wave (Figure 1-1b).

Further decreasing the width of the bars decreases the amplitude of the curve until the amplitude is so small that effectively only a DC level is produced (Figure 1-1c). A spatial resolution element R_N, for purposes of this handbook, is defined as the width of the bars at which the amplitude of the sine wave has decreased by 50% from its maximum value. This width is the pixel.

This width, at the specific range of the hypothetical experiment, subtends a given angle, which is defined as the angular resolution element in the along track dimension, R_ϕ radians.

This handbook describes various categories of spaceborne remote sensors and gives the methods for the calculation of their approximate bandwidth/bit rate. The accurate bandwidth/bit rate of a sensor is dependent on factors not considered herein, such as calibration information synchronization signals, etc. For this reason, the value for bandwidth/bit rate calculated from the forms within should be viewed as a gross first approximation, suitable for the RF spectrum allocator. Additional elements must be known and incorporated to give the exact data rate.

Section 2 provides a means for classifying sensors, in terms of their operation, phenomena sensed, and form of the sensor data. Section 3 explains and gives examples of data rate calculations to illustrate the use of the forms. Section 4 gives the forms for calculating the bandwidth or bit rate of each sensor class. Section 5 shows the methods for converting from analog to digital signals, and for computing the minimum digital bit rate from an analog signal.

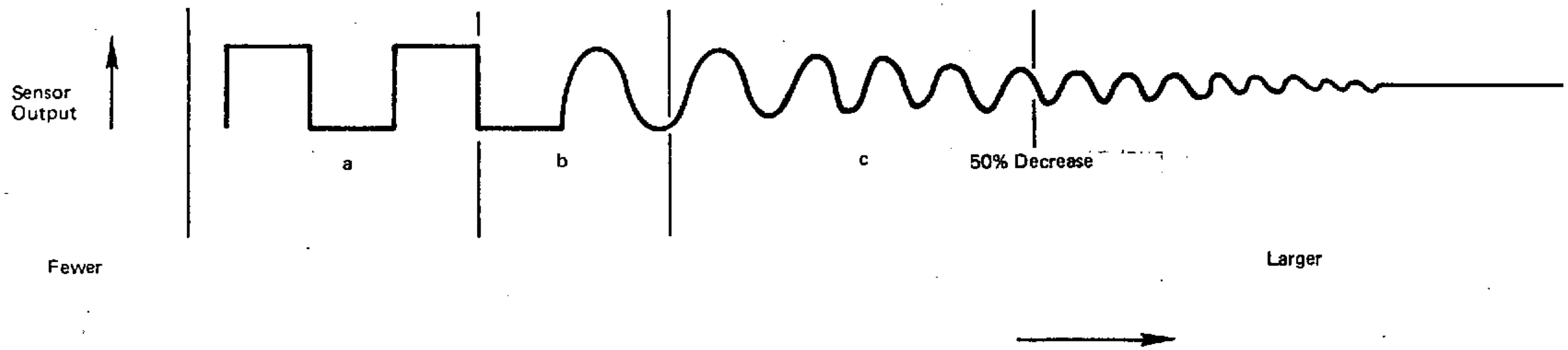


FIGURE 1.1 NUMBER OF BARS SCANNED IN T_{SO} SECONDS

II. SENSOR CLASSIFICATION

This section explains the procedure for identifying the type of sensors under consideration and the location in the handbook containing the correct form for the calculation of its data bandwidth/data rate.

Figure 2.1 is a diagram showing the sensor classification scheme. It serves as a "road map" which guides the user to the correct page and form. The diagram is entered at the point called "spaceborne sensor" and a path followed until one of the 16 end points is reached. The route followed depends on the characteristics of his sensor. If an instrument has more than one channel, a separate calculation must be made for each channel and the results summed to give the total bandwidth/bit rate.

DEFINITION OF TERMS

The definitions of the terms used in Figure 2.1 are presented here (in alphabetical order).

a. Active Sensor: A sensor which supplies energy to the objects or phenomena being observed.

b. Analytical sensor: An analytical sensor is a device which internally processes the received energy and outputs only the result of this processing. The exampl treated is an interferometer. Another example of an analytical sensor.

c. Camera: A passive remote sensor whose output is the intensity of radiation as a function of position in the image plane (e.g., a picture). Each point is the image plane corresponds to a point in the object plane. The input is integrated over the perceived spectral band.

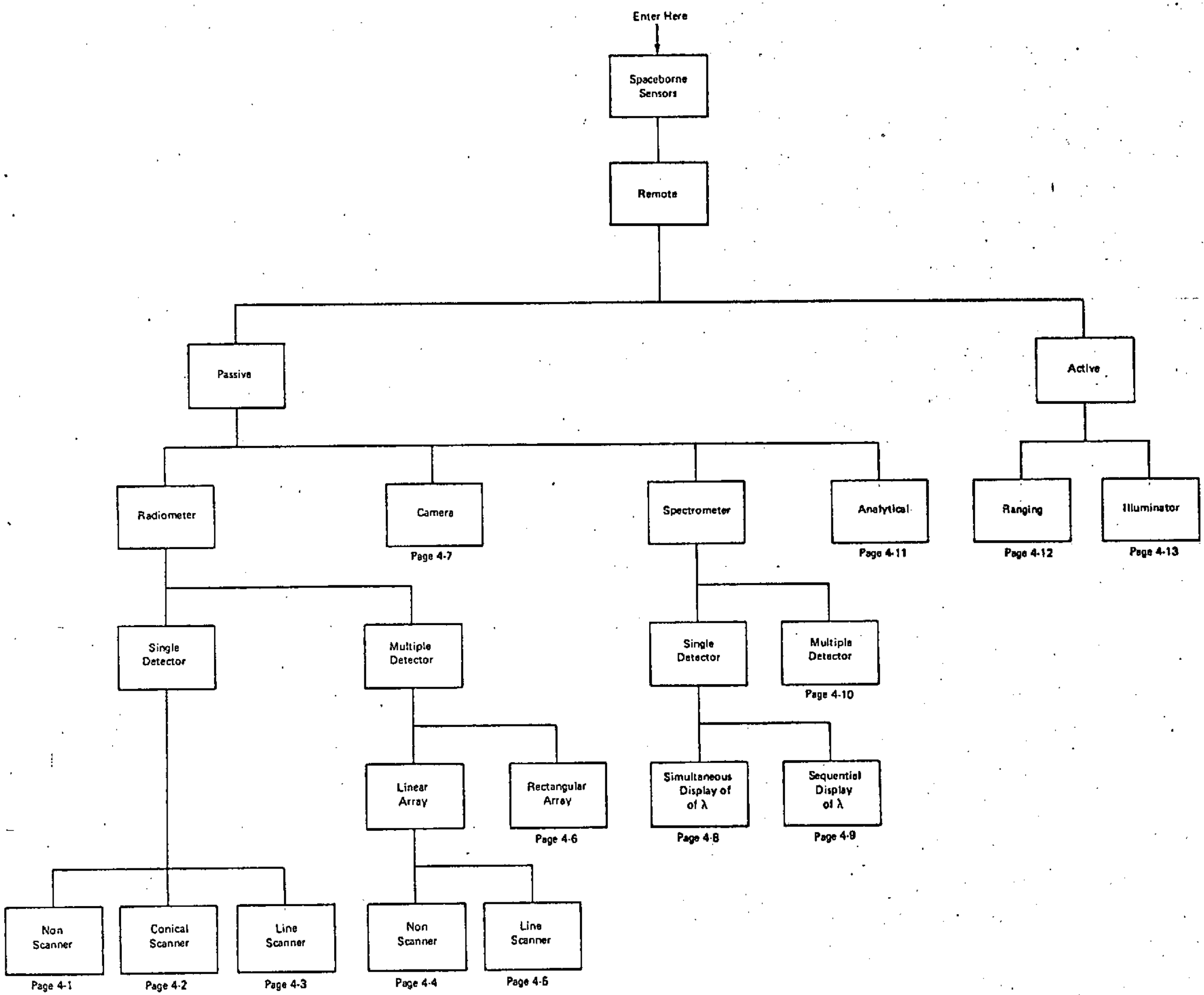


FIGURE 2.1. SENSOR CLASSIFICATION GUIDE

d. Conical Scan: A remote sensor whose scan pattern is a series of circles with increasing or decreasing radii such that the volume of space scanned has the shape of a cone.

e. Illuminator: An active remote sensor one of whose components is used to provide a source of energy used to observe objects or phenomena.

f. Line Scan: A sensor scanning in one direction such that a one dimensional line of the scene is swept across the detector.

g. Linear Array: A linear array is a group of detectors arranged in a line.

h. Multiple Detector: A sensor is said to be of the multiple detector type if it has more than one sensitive element (detector) per data output channel.

i. Non-Scan: A sensor with a fixed angular field of view. For the instrument to view a different volume of space, the sensor's platform must move.

j. Passive Sensor: A remote sensor which observes an object or phenomenon without affecting the energy incident on the object or phenomena

k. Radiometer: A passive remote sensor which has as its output the intensity of radiation, $I[x(t), y(t)]$, as a function of position in the object plane over a wide spectral band.

l. Ranging Sensor: A ranging sensor is an active remote sensor used to obtain information about the distance to, or height of, objects.

m. Rectangular Array: A rectangular array is a group of detectors arranged in a 2 dimensional pattern shaped into a rectangle.

n. Remote Sensor: An instrument which observes phenomena or objects at a distance.

o. Sensor: A device used to make observations of objects or phenomena.

p. Sequential Display: A spectrometer is said to be a sequential display spectrometer if it produces the spectral pattern of the scene sequentially in time (λ (t) dependent on time)., e.g., filter wedge spectrometer.

q. Simultaneous Display: A spectrometer is said to be a simultaneous display spectrometer if it produces the entire spectral pattern of the scene at one time (λ independent of time) e.g., grating spectrometer.

r. Single Detector: A sensor is said to be of the single detector type if it has only one sensitive element (detector) per data output channel.

s. Spectrometer: A passive remote sensor whose output is spectral intensity versus wavelength, $I(\lambda)$. The sensor integrates the incoming radiation over the instantaneous field of view.

Example

In order to illustrate how a sensor may be classified, the following example is presented. Figure 2.2 contains the type of sensor information which might be available to the handbook user about his particular sensor, e.g., a scanning radiometer. He must make use of his information as an aid in following the correct path on the "road map." The handbook user should proceed as follows:

Enter at the point marked sensor and answer a series of questions.

Ques. 1. Is the sensor active or passive?

Answer Passive. This is based on the fact that no mention of any transmitted energy is made and also that the sensor views "emitted radiation from the earth."

Ques. 2. Is the passive sensor a radiometer, camera, spectrometer, or analytical?

Answer A radiometer. This answer was more difficult to reach. It was based on the fact that the sensor "scans the earth's surface from horizon to horizon... by means of a continuously rotating mirror," i.e., the intensity of radiation is a function of position x(t), y(t) where x,y, are functions of time. Although a camera gives intensity vs position, the position is independent of time. The user might also be tempted to call his sensor a spectrometer because it has 2 bands. However, the output is not intensity as a function of wavelength. Each band is considered as a separate channel and requires a separate form.

INSTRUMENT RESUME

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Greenbelt, Maryland 20771

1. TITLE: SCANNING RADIOMETER
2. ACRONYM: SR
3. EXP NO:
4. REVISION DATE: 05/12/71
5. [illegible]: 0006
TLE CONT:

6. PRINCIPAL INVESTIGATOR: SEMUNDER, G. (T-MON)
7. ORGANIZATION: GODDARD SPACE FLT CENTER
8. TELEPHONE: 301-982-5042
9. CO-INVESTIGATOR:
10. ORGANIZATION:
11. TELEPHONE:

12. CONTRACT TYPE: FP
13. CONTRACT NUMBER:
14. CLASH INDEX NUMBER:
15. START DATE:
16. [illegible]:
17. STATUS: OPERATIONAL

18. MONITOR: GARBACZ, M.
19. AGENCY: NASA HDQTRS
20. PGM OFFICE: OSSA/SAT
21. TELEPHONE: 202-963-7101

22. VENDOR: SANTA BARBARA RES CENTER
23. LOCATION: GOLETA,CALIF
24. FLIGHT DATE: 2/70
25. LEAD TIME: NA

26. INSTRUMENT TYPE: RADIOMETER, VISIBLE/IR SCANNING
27. [illegible]: UNC

28. APPLICATION: MET,ATM-PHYS,PART-FLD
29. SPACECRAFT: ITOS-1

30. PURPOSE

PRIMARY-TO MEASURE EMITTED RADIATION FROM THE EARTH DURING DAY AND NIGHT AND TO MEASURE REFLECTED RADIATION FROM THE EARTH DURING DAYTIME. THE SYSTEM PERMITS DETERMINATION OF THE SURFACE TEMPERATURE OF THE GROUND, SEA, OR CLOUD TOPS THAT ARE VIEWED BY THE RADIOMETER.

31. PRINCIPLES OF OPERATION

THIS SCANNING RADIOMETER SYSTEM CONSISTS OF 2 REDUNDANT RADIOMETERS WITH SUPPORTING COMPONENTS. EACH HAS 2 DATA CHANNELS: AN IR (10.5-12.5 MICRONS) AND VISIBLE (0.52-0.73 MICRON) BOTH WITH AN INSTANTANEOUS FOV OF 0.3 DEG. THE RADIOMETER SCANS THE EARTH'S SURFACE FROM HORIZON TO HORIZON, PERPENDICULAR TO THE ORBITAL PLANE BY MEANS OF A CONTINUOUSLY ROTATING MIRROR(48 RPM) WHICH IS INCLINED 45 DEG TO ITS AXIS OF ROTATION. THE IR CHANNEL IS CALIBRATED AT THE COLD EXTREME BY MEASURING THE RESPONSE TO OUTER SPACE AND ON THE WARM SIDE BY MEASURING THE IR RADIATION FROM INSIDE THE RADIOMETER HOUSING. THE VISIBLE CHANNEL IS CALIBRATED SEPARATELY. IN OPERATION, RADIATION REFLECTS FROM THE ROTATING MIRROR TO THE COLLECTING OPTICS, A 5-IN DIAM CASSEGRAINIAN SYSTEM, AND IS THEN FOCUSED ONTO THE BEAM SPLITTER (DICHROIC MIRROR). THE IR PASSES THROUGH AND IS MEASURED BY A SOLID-STATE RADIANT ENERGY DETECTOR (THERMISTOR BOLOMETER). THE VISIBLE IS REFLECTED FROM THE BEAM SPLITTER AND PASSES THROUGH A 0.52-0.73 MICRON WAVELENGTH FILTER ONTO A PHOTOVOLTAIC SILICON DETECTOR. DATA ARE RECORDED ON TAPE. THE IR CHANNEL ALSO IS COMPATIBLE WITH THE APT SYSTEM PRODUCING A DIRECT READOUT IR SYSTEM.

32. PHENOMENA OBSERVED

ENERGY IN THE INFRARED AND VISIBLE REGION OF THE SPECTRUM

33. MEASUREMENT RANGE

VISIBLE BRIGHTNESS: 50-10,000 FT-LAMBERTS; IR TEMP:180-330 DEG K

34. PRECISION AND ACCURACY

1.0 K DEG AT 300 DEG K; 4.0 K DEG AT 185 DEG K

35. SPECTRAL RANGE: 0.52 TO 12.5 MICRONS
36. SPECTRAL RESOLUTION:
37. TIME CONSTANT: CONTINUOUS

38. FIELD OF VIEW: 150.0 DEG
39. GROUND SWATH: LIMB-TO-LIMB (4100 NM) FROM 750 NM ALT

40. ANGULAR RESOLUTION: 0.4 DEG
41. SPATIAL RESOLUTION: 2 NM VISIBLE, 4 NM IR FROM 750 NM ALTITUDE

42. POINTING ACCURACY:
43. POINTING RATE:
44. ALTITUDE: MED CIRCULAR
45. INCLINATION: SUN-SYNCH. RETROGRADE

46. SPECIAL REQUIREMENTS

RADIOMETERS MUST BE ABLE TO SCAN 150 DEG WITHOUT OBSTRUCTIONS

47. COMPONENTS

2 RADIOMETER-ELECTRONICS SYSTEMS, PROCESSOR, TAPE RECORDER

48. WEIGHT: 40 LB
49. VOLUME: 0.5 CU FT
50. AVERAGE POWER: 14 WATTS
51. STANDBY POWER:
52. PEAK POWER:
53. MTBF: 1 YEAR

54. RF INTERFERENCE:
55. MAGNETIC INTERFERENCE:
56. NUCLEAR INTERFERENCE:
57. THERMAL INTERFERENCE: SENSITIVE
58. SHIELDING:

59. CALIBRATION: 2 COLD, 1 HOT EACH SCAN
60. DATA RECOVERY: DELAYED AND REALTIME
61. FREQUENCY OF OBSERVATION: NIGHTTIME/DAYTIME

62. TELEMETRY REQUIREMENTS

BASEBAND BANDWIDTH IS 7.2 KHZ.

63. ADVANTAGES AND LIMITATIONS

HIGHER CALIBRATION ACCURACY IN VISIBLE THAN PRESENT CAMERAS, NOT SUBJECT TO SHADING. PROVIDES DAY AND NIGHT REALTIME IR DATA.

64. REFERENCES

1)DESIGN STUDY REPORT FOR THE IMPROVED TOS(ITOS)SYSTEM,V.1,2,3. RCA ASTRO-ELECTRONICS, CONTRACT NO. NAS5-9034, JUNE 7,68.***2) GOLDBERG,I.: METEOROLOGICAL IR INSTRUMENTS FOR SATELLITES, PRESENTED AT 13TH ANNUAL TECH. SYMP. OF SOCIETY OF PHOTO-OPTICAL INSTRUMENTATION ENGINEERS, AUG. 22, 1968.

65. HISTORICAL REMARKS

SCHEDULED FOR LAUNCH IN 1970

66. DIAGRAMS

FIGURE 2-2

Ques. 3. Do I have a single or multiple detector sensor?

Answer Single detector. This answer was based on the fact that the sensor has two bands and two data output channels hence, <u>one</u> detector for each channel.

Ques. 4. Do I have a nonscanning, conical scanning or line scanning sensor?

Answer A line scanner. This answer was based on an understanding of the description of the sensor scan. The sensor "scans . . . from horizon to horizon. . . by means of a continuously rotating mirror (48 rpm) which is inclined 45° to its axis of rotation."

Having answered the above questions, the user sees that he has a passive remote sensor, called a line scanning radiometer. The form for the calculation of the bandwidth/data rate is found on page 4-3, as indicated in Figure 2.1.

The following section describes the use of the form found on page 4-3 with the scanning radiometer described in Figure 2.2 to calculate the approximate data rate of that instrument.

III. USE OF DATA CALCULATION FORM

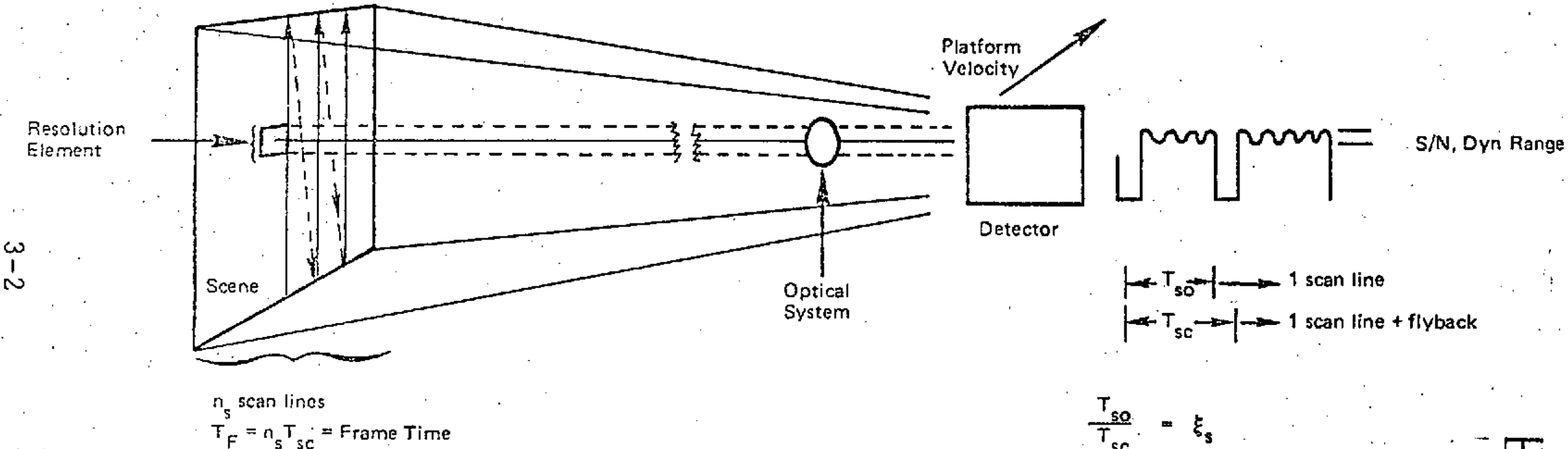
The instrument considered, the one described in the previous sections, is the scanning radiometer which flew on ITOS-1. Its characteristics have been given in the resume in Figure 2-2, and the correct form to use is found on page 4-3 as determined in Section 2.

For convenience this form is reproduced as Figure 3-1. As can be seen, opposite the calculation form is a diagram showing the sensor and defining various parameters used in the calculation.

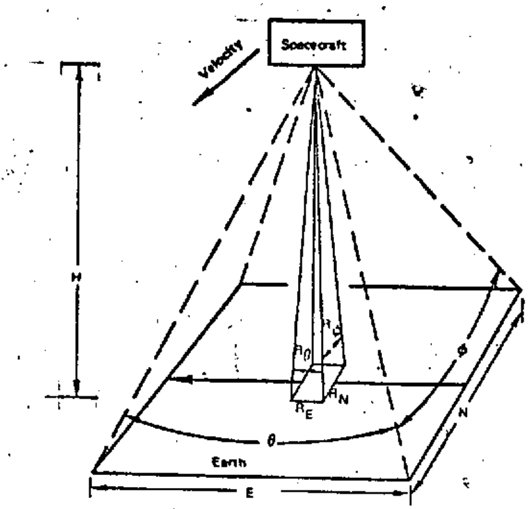
The form itself has five columns, each containing information or providing space for information to be inserted.

Under "Input", the characteristics of the instrument which are to be specified are listed. Where the word "OR" appears within an input category, an alternative characteristic is indicated. Only inputs from category A are required unless otherwise directed by Column 4. "Units" indicates the units for which a value for the input characteristic is to be supplied under "Value". If the selection of one particular input alternative necessarily requires the specification of other inputs, these others are listed under "Other Required Inputs". Finally the equation(s) to be used to calculate bandwidth/bit rate are given in the extreme righthand column.

The completed format for the Scanning Radiometer is shown in Figure 3-2a and 3-2b. The instrument identification is entered at the top of the form. Also at the top of the form is a place to identify the particular channel or band being considered, if the instrument has more than one. The scanning radiometer has two channels, one in the IR region and the other in the visible. Figure 3-2a was used for the former and 3-2b for the latter. The ground viewing conventions used are shown in Figure 3-3.



SINGLE DETECTOR LINE-SCANNING RADIOMETER



GROUND VIEWING CONVENTIONS

Passive Remote Sensor
Radiometer
Single Detector Line Scan

Instrument: ____________ Channel: ________________

Input	Unit	Value	Other Required Inputs	Calculation Equations
A. Time Element				
1. T_{SO}	seconds	______ or	(B1a) and (B1b), C (B2a) (B2b), and (B2c), C	$B = \theta/2R_\theta T_{SO}$ Hz
or 2 a. T_{SC}	seconds	______ or	(B1a) and (B1b), C	$B = \theta/2R_\theta T_{SC}\xi_s$ Hz
b. ξ_s		______	(B2a) (B2b) and (B2c), C	
or 3. T_F	seconds	______ or	(B1), C (B2), C	$B = \dfrac{\theta\phi}{2R_\theta R_\phi T_F}$ Hz
B. Spatial Element				
1. Angular				
a. θ	radians	______		
b. R_θ	radians	______		
c. ϕ	radians	______		
d. R_ϕ	radians	______		
2. Scene Referenced				
a. E	km	______		$\theta = 2\tan^{-1}(E/2H)$
b. R_E	km	______		$R_\theta = 2\tan^{-1}(R_E/2H)$
c. N	km	______		$\phi = 2\tan^{-1}(N/2H)$
d. R_N	km	______		$R_\phi = 2\tan^{-1}(R_N/2H)$
e. H (altitude)	km	______		
C. Intensity Element				
1. S/N		______		$S/N = \dfrac{\text{Dynamic Range}}{\text{Precision}}$
or 2.a. Dynamic Range		______		
b. Precision		______		

FIGURE 3-1

Passive Remote Sensor
Radiometer
Single Detector Line Scan

Instrument: ITOS-1 Scanning Radiometer   Channel: IR

Input	Unit	Value	Other Required Inputs	Calculation Equations
A. Time Element				
1. T_{SO}	seconds	____	(B1a) and (B1b), C or (B2a) (B2b), and (B2c), C	$B = \theta/2R_\theta T_{SO}$ Hz
or 2 a. T_{SC}	seconds	1.25	(B1a) and (B1b), C or (B2a) (B2b) and (B2c), C	$B = \theta/2R_\theta T_{SC} \xi_s$ Hz
b. ξ_s		0.42		
or 3. T_F	seconds	____	(B1), C or (B2), C	$B = \frac{\theta \phi}{2R_\theta R_\phi T_F}$ Hz
B. Spatial Element				
1. Angular				
a. θ	radians	2.62		B = 575 Hz
b. R_θ	radians	0.007		
c. ϕ	radians	____		
d. R_ϕ	radians	____		
2. Scene Referenced				
a. E	km	____		$\theta = 2 \tan^{-1} (E/2H)$
b. R_E	km	____		$R_\theta = 2 \tan^{-1} (R_E/2H)$
c. N	km	____		$\phi = 2 \tan^{-1} (N/2H)$
d. R_N	km	____		$R_\phi = 2 \tan^{-1} (R_N/2H)$
e. H (altitude)	km	____		
C. Intensity Element				
1. S/N		____		S/N = Dynamic Range / Precision
or 2.a. Dynamic Range		$180^\circ K - 330^\circ K$		
b. Precision		$1^\circ K$		

FIGURE 3-2a.

Passive Remote Sensor
Radiometer
Single Detector Line Scan

Instrument: ITOS-1 Scanning Radiometer Channel: Visible

Input	Unit	Value	Other Required Inputs	Calculation Equations
A. Time Element				
1. T_{SO}	seconds	____	or (B1a) and (B1b), C; (B2a) (B2b), and (B2c), C	$B = \theta / 2R_\theta T_{SO}$ Hz
or 2 a. T_{SC}	seconds	1.25	or (B1a) and (B1b), C; (B2a) (B2b) and (B2c), C	$B = \theta / 2R_\theta T_{SC} \xi_s$ Hz
b. ξ_s		0.42		
or 3. T_F	seconds	____	(B1), C or (B2), C	$B = \frac{\theta \phi}{2R_\theta R_\phi T_F}$ Hz
B. Spatial Element				
1. Angular				
a. θ	radians	2.62		B = 575 Hz
b. R_θ	radians	0.007		
c. ϕ	radians	____		
d. R_ϕ	radians	____		
2. Scene Referenced				
a. E	km	____		$\theta = 2 \tan^{-1} (E/2H)$
b. R_E	km	____		$R_\theta = 2 \tan^{-1} (R_E/2H)$
c. N	km	____		$\phi = 2 \tan^{-1} (N/2H)$
d. R_N	km	____		$R_\phi = 2 \tan^{-1} (R_N/2H)$
e. H (altitude)	km	____		
C. Intensity Element				
1. S/N		200:1		S/N = Dynamic Range / Precision
or 2.a. Dynamic Range		____		
b. Precision		____		

FIGURE 3-2b

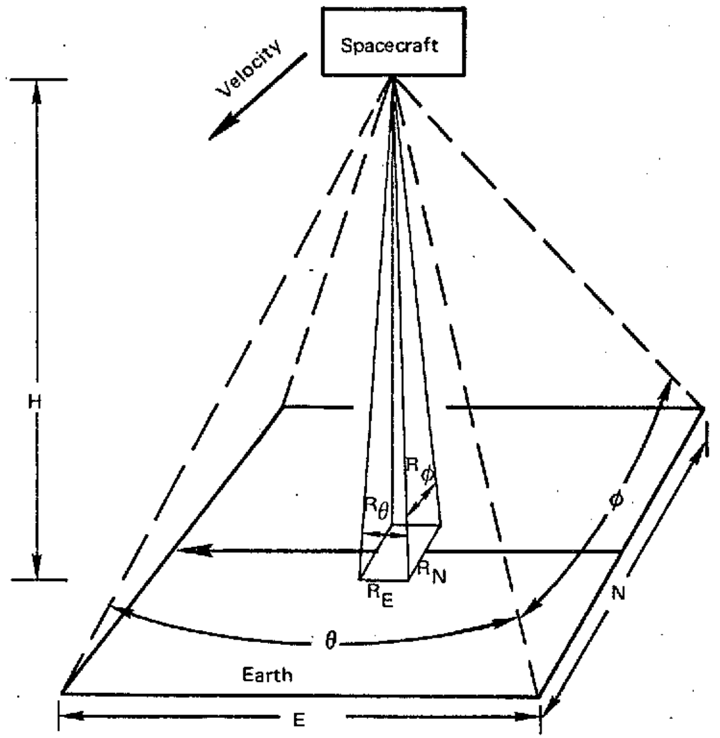


FIGURE 3-3. GROUND VIEWING CONVENTIONS

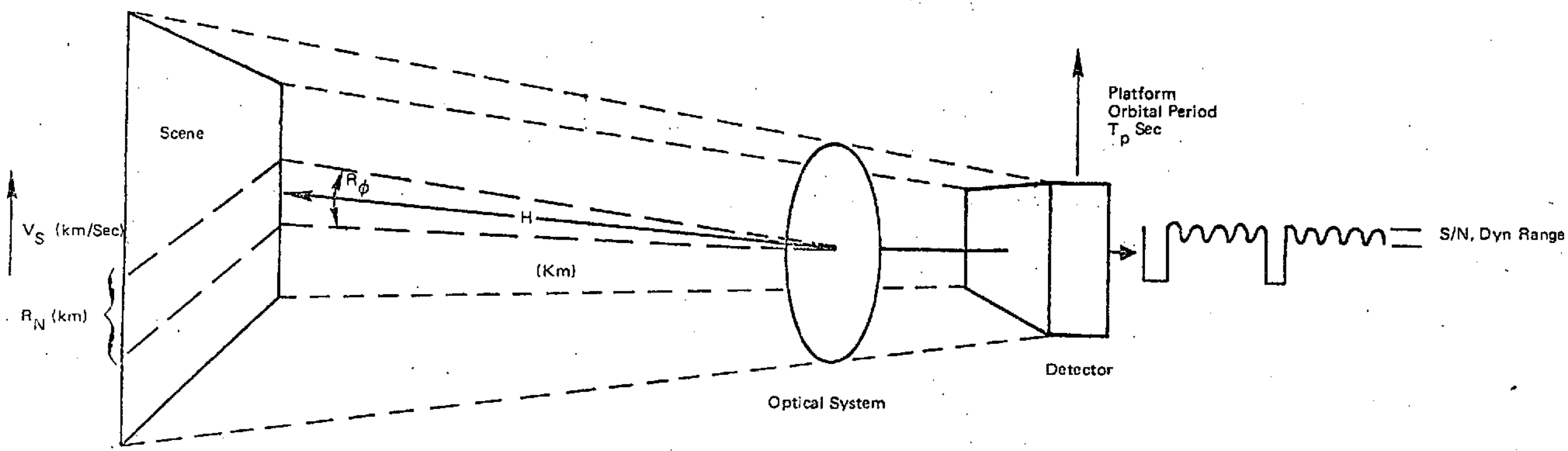
Referring to Figure 3-2a, the time element specified is the total scan time, 1.25 seconds corresponding to 48 rpm. The scan efficiency ξ_s is 0.42, found by dividing the total scan of the mirror, 2π radians, by the field of view, 2.62 radians.

Having selected T_{SC} as the time element, the other required outputs are seen to be either θ and R_θ or E and R_E. In addition an intensity element must be specified if the output will be digitized. In Figure 3-2a, values for θ, R_θ, and Dynamic Range and Precision were inserted, based on the information supplied by the instrument resume.

The bandwidth, B, may now be calculated from the equation $B=\theta/2 R_\theta T_{SC} \xi_S$ which appears opposite the alternative selected, i.e. T_{SC} and (B1a) and (B1b), C. The result of the calculation, B = 575Hz, appears on the right side of the sheet, below the list of calculation equations.

The alternatives selected in Figure 3-2b for the visible channel are identical except for the intensity element, C. The bandwidth of the detector output is therefore the same. The total bandwidth of the instrument is the sum of the two bandwidths or 1050 Hz.

IV. COMPUTATIONAL FORMS



V_S = Velocity of Projection of Sensor Onto Scene

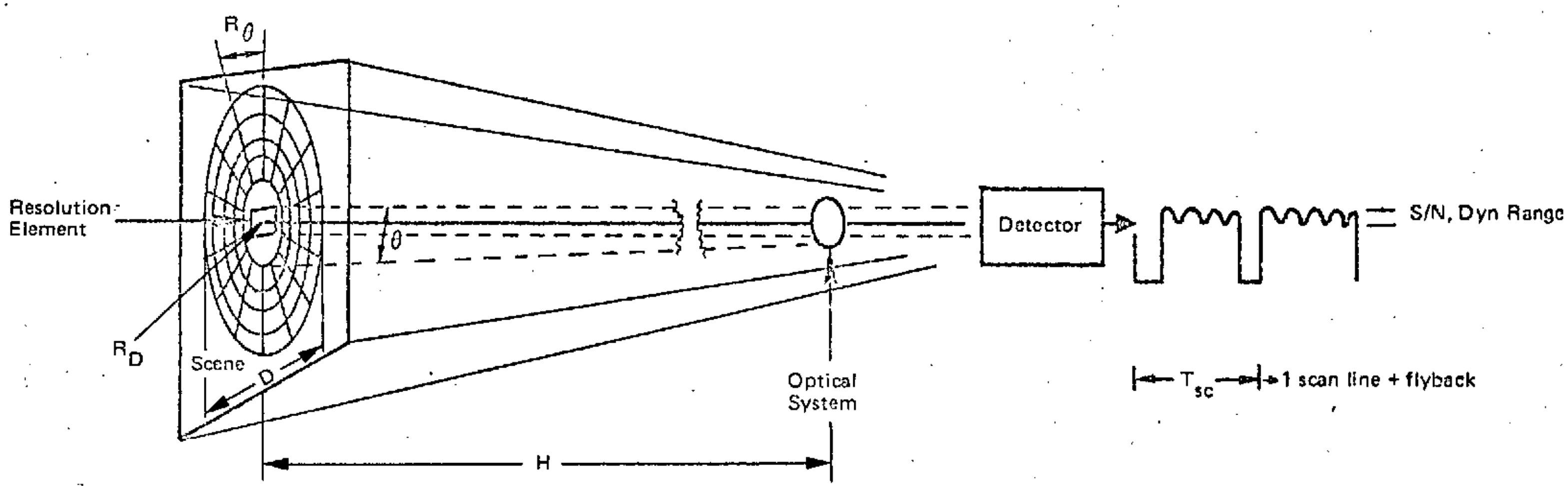
SINGLE DETECTOR NON-SCANNING RADIOMETER

Passive Sensor
Radiometer
Single Detector
Non-scanning

Instrument:________________ Channel________________

Input	Unit	Value	Other Req'd Inputs	Calculation Equations
A. Sensor Velocity or Time Element				
1. T_p	second	_____	B, C	$B = \frac{40{,}000^*}{2R_N T_P}$ Hz
or 2. V_S	km/second	_____	B, C	$B = \frac{V_s}{2R_N}$ Hz
B. Resolution Element				
1. R_N	km	_____		
or 2a. R_ϕ	radians	_____		$R_N = 2H \tan\left(\frac{R_\phi}{2}\right)$
b. H	km	_____		
C. Intensity Element				
1. S/N		_____		$S/N = \frac{\text{Dynamic Range}}{\text{Precision}}$
or 2.a. Dynamic Range		_____		
b. Precision		_____		

*The approximate earth's circumference is 40,000 km.



T_F = Frame Time

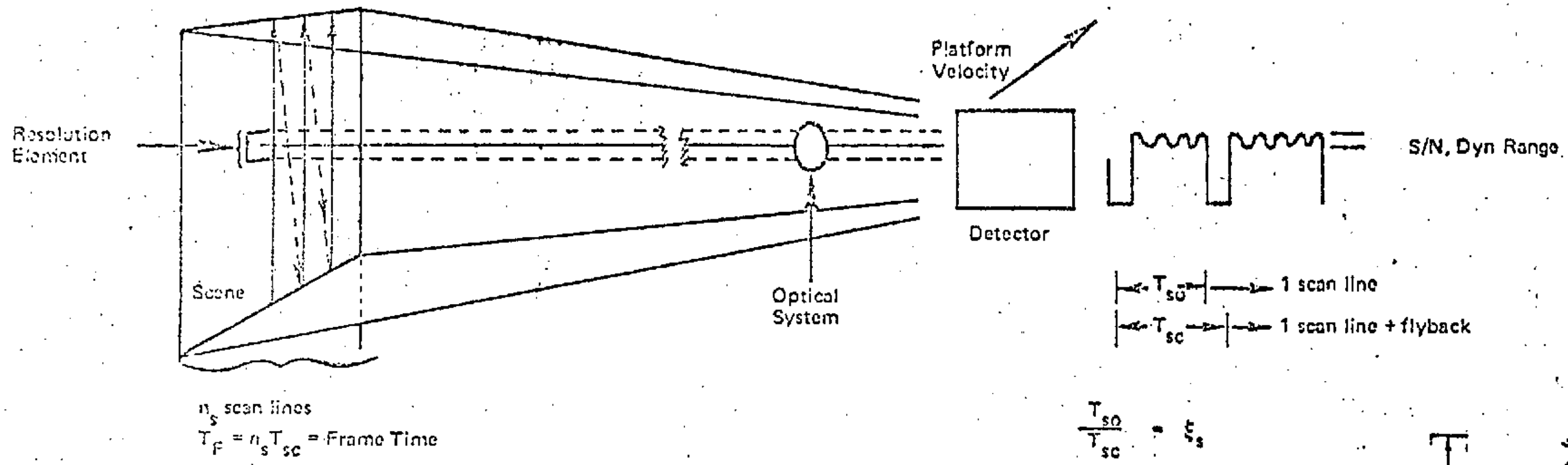
$$\frac{T_{so}}{T_{sc}} = \xi_s$$

SINGLE DETECTOR CONICAL SCANNING RADIOMETER

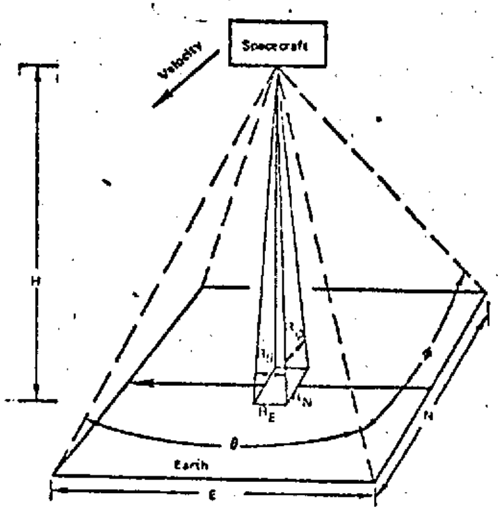
Passive Remote Sensor
Radiometer
Single Detector Conical Scanner

Instrument: ____________ Channel: ________________

Input	Unit	Value	Other Required Inputs	Calculation Equations
A. Spatial Element				
1. a. θ (angular swath)	radians	______		$B = \dfrac{\pi \tan^2 \frac{\theta}{2}}{2\, \xi_s T_F \tan^2 \frac{(R\theta)}{2}}$
b. R_θ (angular resolution)	radians	______		
or				
2. a. D (ground swath)	km	______		$\frac{\theta}{2} = \tan^{-1} \left(\frac{D}{H} \right)$
b. R_D (spatial resolution)	km	______		$\frac{R_\theta}{2} = \tan^{-1} \left(\frac{R_D}{H} \right)$
c. H (altitude)	km	______		
B. Time Element				
1. a. T_F	seconds	______		
b. ξ_s (Scan efficiency)		______		
C. Intensity Element				
1. S/N		______		S/N = $\dfrac{\text{Dynamic Range}}{\text{Precision}}$
or				
2. a. Dynamic Range		______		
b. Precision		______		



SINGLE DETECTOR LINE-SCANNING RADIOMETER

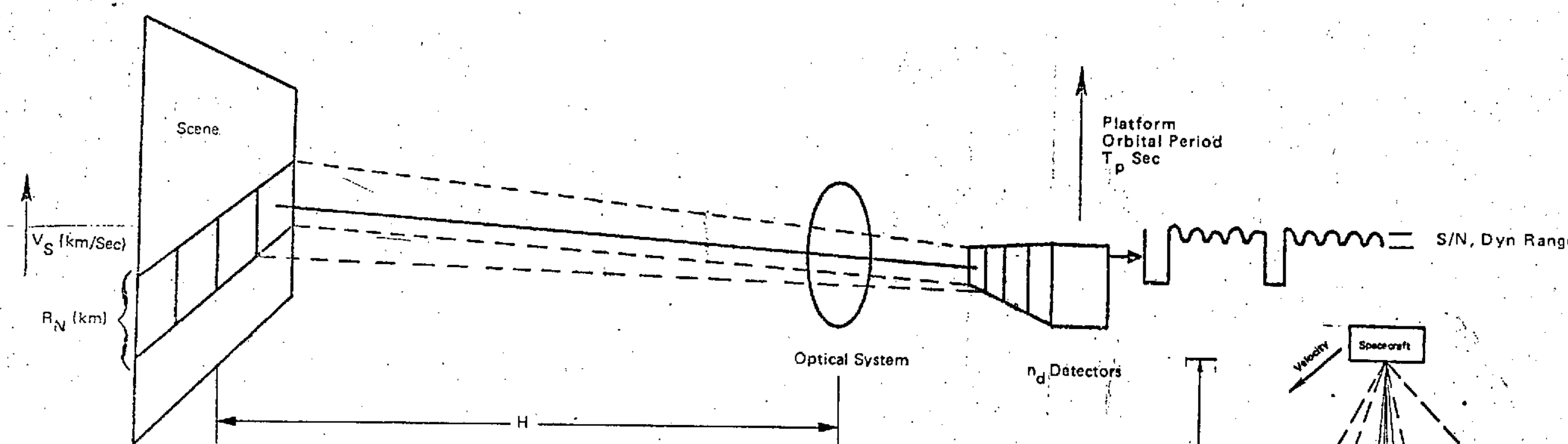


GROUND VIEWING CONVENTIONS

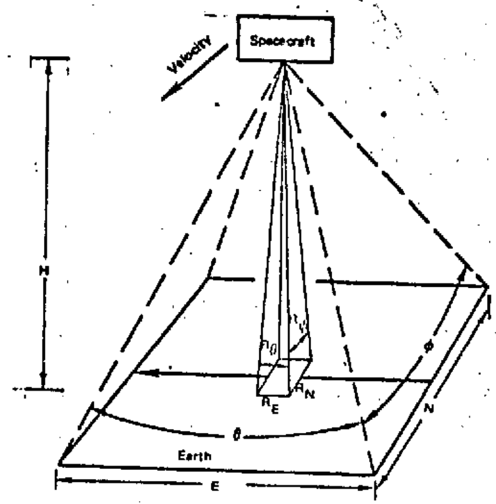
Passive Remote Sensor
Radiometer
Single Detector Line Scan

Instrument:__________ Channel:__________

Input	Unit	Value	Other Required Inputed	Calculation Equations
A. Time Element				
1. T_{SO}	seconds	_____	(B1a) and (B1b), C or (B2a) (B2b), and (B2c), C	$B = \theta/2R_\theta T_{SO}$ Hz
or 2 a. T_{SC}	seconds	_____	(B1a) and (B1b), C or (B2a) (B2b) and (B2c), C	$B = \theta/2R_\theta T_{SC}\xi_s$ Hz
b. ξ_s		_____		
or 3. T_F	seconds	_____	(B1), C or (B2), C	$B = \dfrac{\theta\phi}{2R_\theta R_\phi T_F}$ Hz
B. Spatial Element				
1. Angular				
a. θ	radians	_____		
b. R_θ	radians	_____		
c. ϕ	radians	_____		
d. R_ϕ	radians	_____		
2. Scene Referenced				
a. E	km	_____		$\theta = 2\tan^{-1}(E/2H)$
b. R_E	km	_____		$R_\theta = 2\tan^{-1}(R_E/2H)$
c. N	km	_____		$\phi = 2\tan^{-1}(N/2H)$
d. R_N	km	_____		$R_\phi = 2\tan^{-1}(R_N/2H)$
e. H (altitude)	km	_____		
C. Intensity Element				
1. S/N		_____		$S/N = \dfrac{\text{Dynamic Range}}{\text{Precision}}$
or 2.a. Dynamic Range		_____		
b. Precision		_____		



MULTIPLE DETECTOR LINEAR ARRAY
NON-SCANNING RADIOMETER



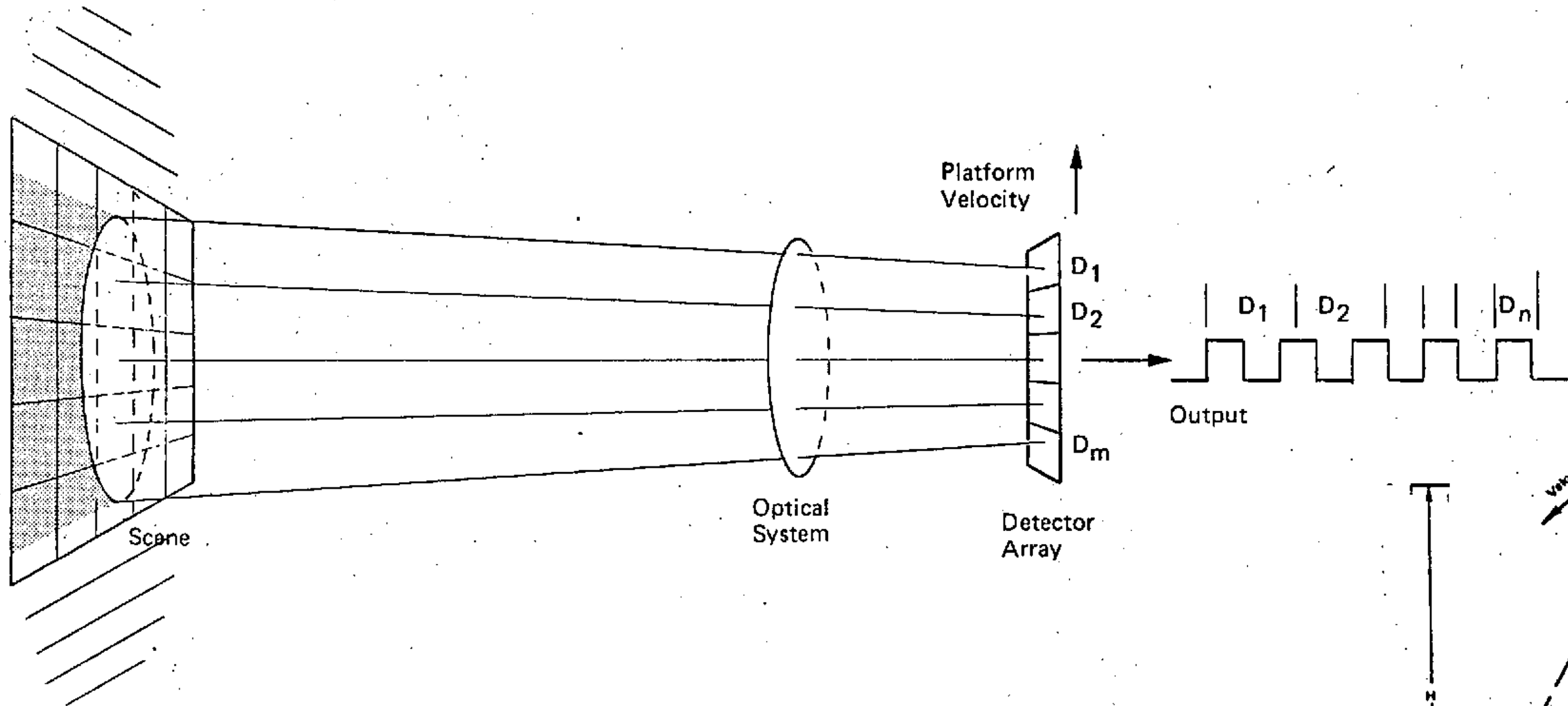
GROUND VIEWING CONVENTIONS

Passive Remote Sensor
Radiometer
Multiple Detector
Linear Array
Non Scanner

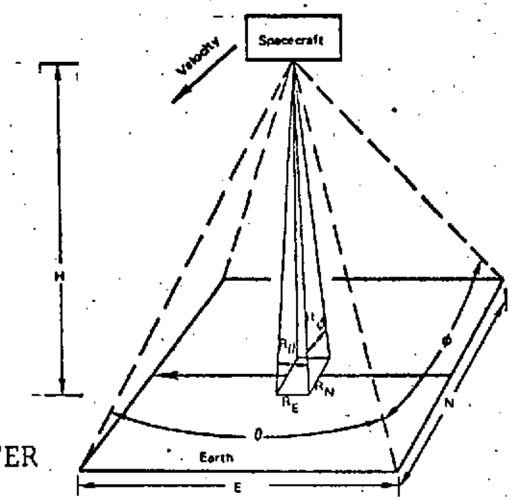
Instrument: ______________ Channel: ______________

Input	Unit	Value	Other Required Inputs	Calculation Equations
A. Time or Velocity	Element			
1. T_p	Seconds	____	B, C	$B = \frac{40,000\, n_d}{2 R_N T_p}$ Hz
or 2. V_s	km/second	____	B, C	$B = \frac{V_s\, n_d}{2 R_n}$ Hz
B. Spatial Element				
1. R_N	km	____		
or 2.a. R_ϕ	radians	____		$R_N = 2H \tan\left(\frac{R_\phi}{2}\right)$
b. H (altitude)	km	____		
C. Array Size				
1. n_d (number of elements)		____		
D. Intensity Element				
1. S/N		____		$S/N = \frac{\text{Dynamic Range}}{\text{Precision}}$
or 2. a. Dynamic Range		____		
b. Precision		____		

*The approximate earth's circumference is 40,000 km.



MULTIPLE DETECTOR, LINEAR ARRAY, LINE SCAN RADIOMETER

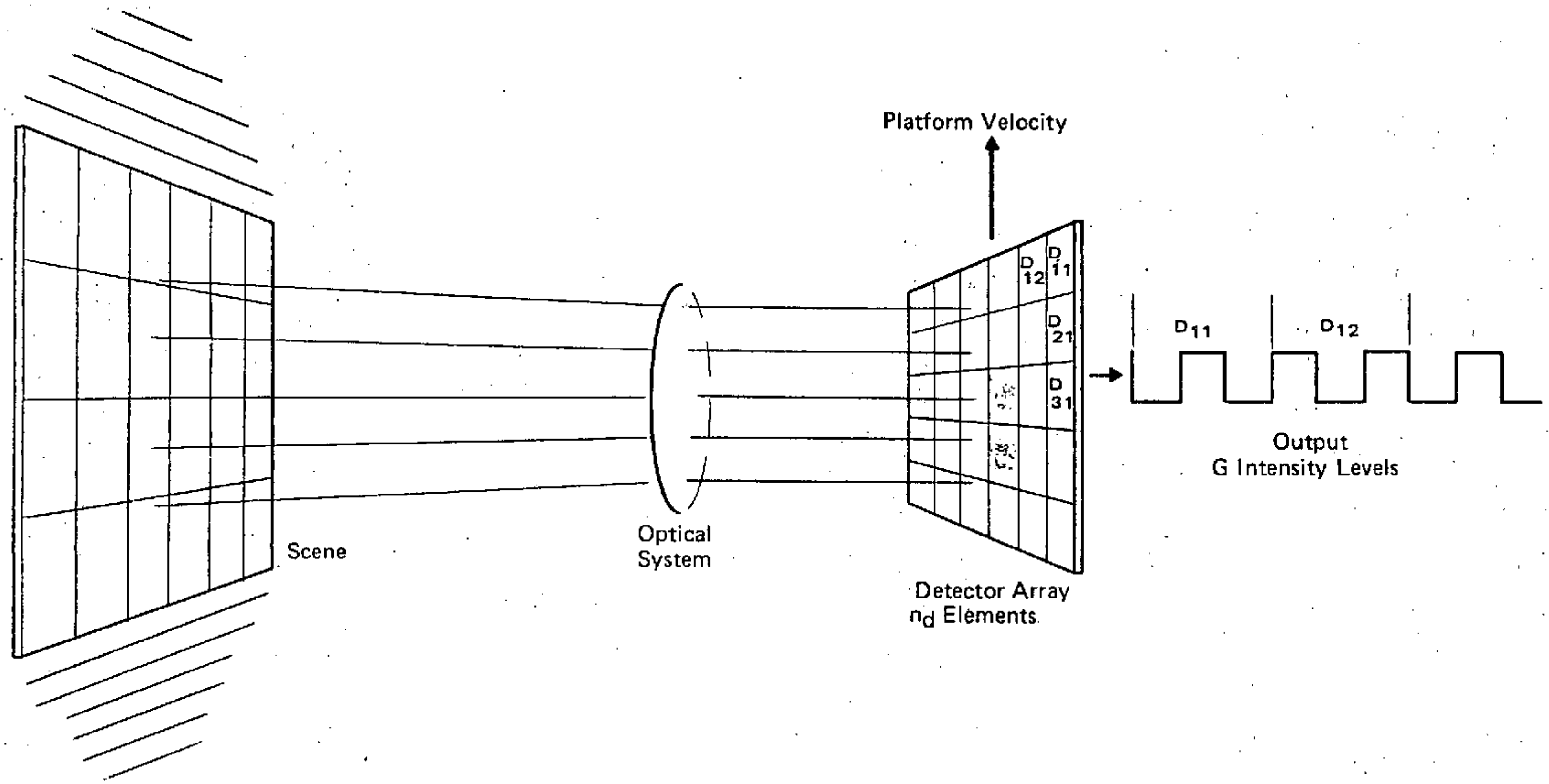


GROUND VIEWING CONVENTIONS

Passive Remote Sensor Radiometer
Multiple Detector
Linear Array Line Scanner

Instrument:________________ Channel:____________

Input	Unit	Value	Other Required Inputs	Calculation Equations
A. Time Element				
1. T_{SO} (time/scan spent viewing scene)	seconds	_____	B, C, D	$\frac{[\log_2 (S/N)] n_d \theta / R_\theta}{T_{SO}}$ BPS
or				
2.a. T_{SC} (Complete scan period)	seconds	_____	B, C, D	$T_{SO} = T_{SC} \xi_s$
b. ξ_s (scan efficiency)				
B. Spatial Element				
1.a. θ (scan angle)	radians	_____		
b. R_θ (angular resolution)	radians	_____		
or				
2.a. E (swath coverage)	Km	_____		$\theta = \frac{1}{2} \tan^{-1} (2\ E/H)$
b. R_E (spatial resolution in direction of scan)	Km	_____		$R_\theta = \frac{1}{2} \tan^{-1} (2\ R_E/H)$
c. H (orbital altitude)	Km	_____		
C. Array				
1. n_d (number of elements)		_____		
D. Intensity Element				
1. S/N		_____		$S/N = \frac{\text{Dynamic Range}}{\text{Precision}}$
or				
2.a. Dynamic Range		_____		
b. Precision		_____		

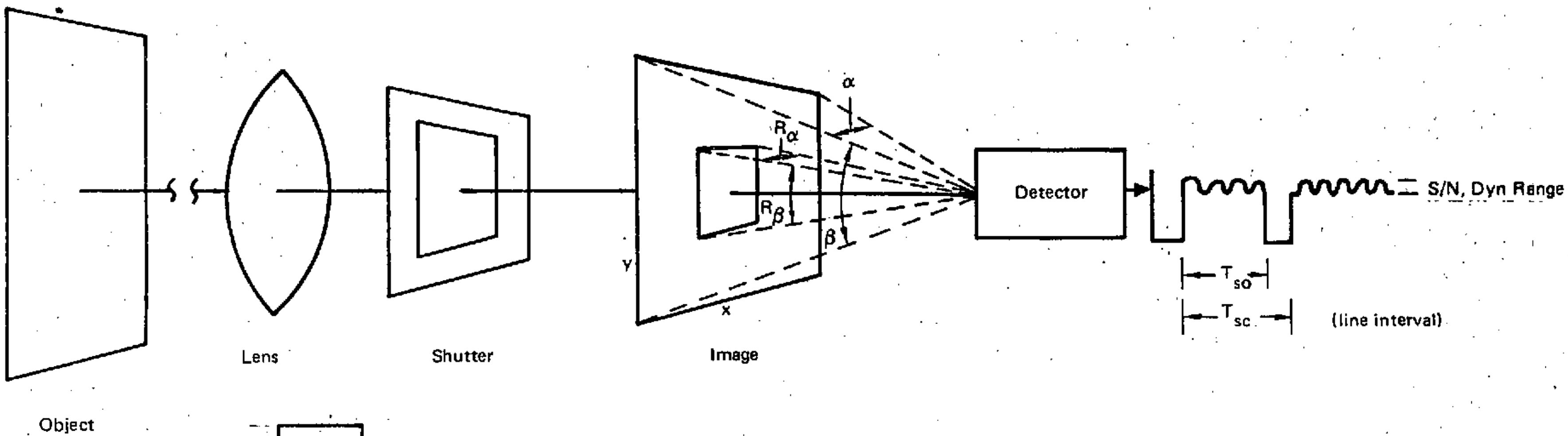


• MULTIPLE DETECTOR, RECTANTULAR ARRAY, RADIOMETER

Passive Radiometer
Multiple Detector
Rectangular Array

Instrument:__________ Channel:__________

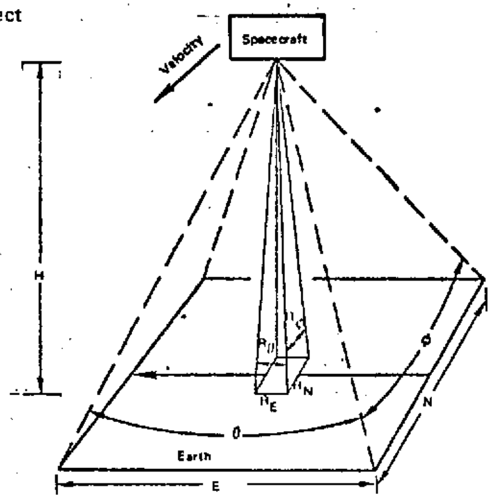
Input	Unit	Value	Other Required Inputs	Calculation Equations
A. Time Element				
1. T_F	seconds	____	B,C	$C = \frac{n_d \log_2(S/N)}{T_F}$ bits per sec.
B. Array				
1. n_d (number of elements)		____		
C. Intensity Element				
1. S/N		____		
or				
2.a. Dynamic Range		____		$S/N = \frac{\text{Dynamic Range}}{\text{Precision}}$
b. Precision		____		
or				
3. G (number of levels)		____		$S/N = G$



n_s scan lines (unblanked)

$T_F = n_s T_{sc}$ = Frame Time

$$\frac{T_{so}}{T_{sc}} = \xi_s$$



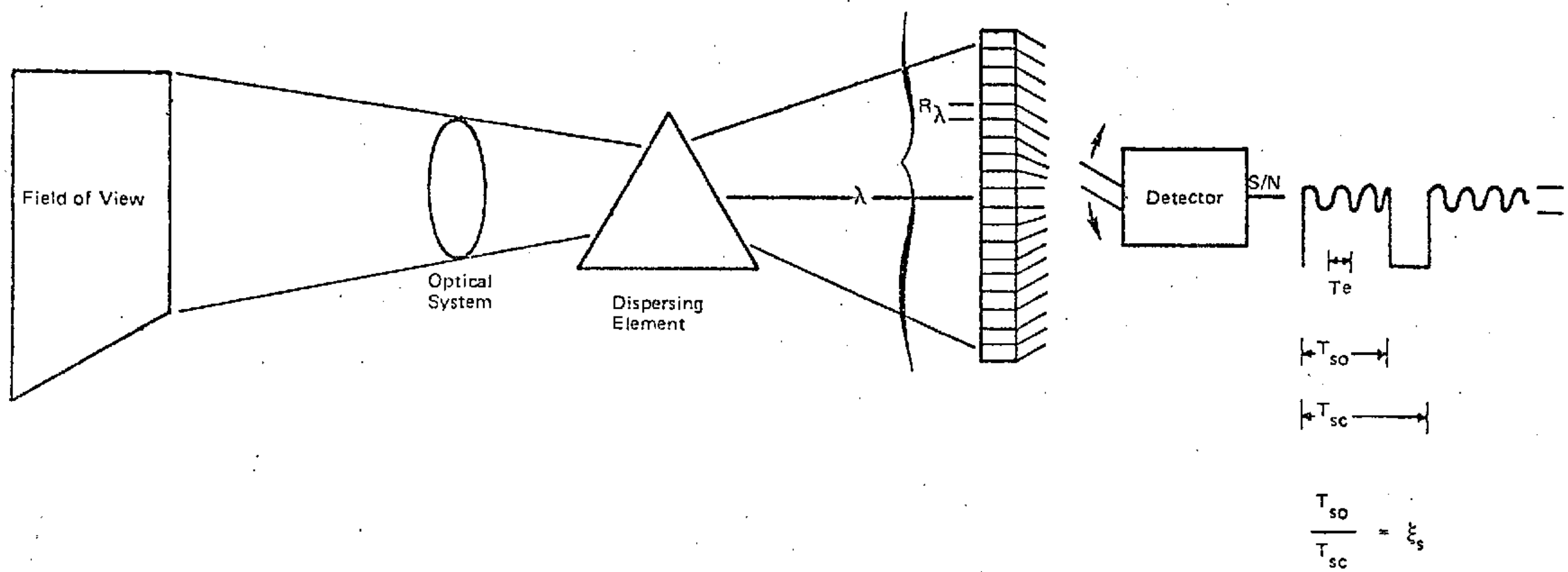
GROUND VIEWING CONVENTIONS

CAMERA

CAMERA

Instrument: ______________________ Channel: ______________________

Input	Unit	Value	Other Required Inputs	Calculations Equations
A. Time Element				
1. T_{SO}	seconds	______	(B_1, or B_2, or B_5, or B_7, and B_9), C	$B = \frac{x/R_x}{2T_{SO}}$ or $B = \frac{\alpha/R_\alpha}{2T_{SO}}$ Hz
or 2.a. T_{SC}	seconds	______	(B_1, or B_2, or B_5, or B_7 and B_9), C	$B = \frac{x/R_x}{2T_{SC}\xi_s}$ or $B = \frac{\theta/R_\theta}{2T_{SC}\xi_s}$
b. ξ_s				or $B = \frac{\alpha/R_\alpha}{2T_{SC}\xi_s}$ Hz
or 3. T_F	seconds	______	(B_1 and B_3)	$B = \frac{x/R_x \cdot y/R_y}{2T_f\xi_s}$ Hz
			or (B_2 and B_4)	$B = \frac{\alpha/R_\alpha \cdot B/R_B}{2T_f\xi_s}$ Hz
			or (B_5, B_6, B_7, B_8, and B_9), C	$B = \frac{\theta/R_\theta \cdot \phi/R_\phi}{2T_f\xi_s}$ Hz
B. Spatial Element				
1.a. X	m	______		
b. R_y	m	______		
2.a. α	radians	______		
b. R_α	radians	______		
3.a. Y	m	______		
b. R_y	m	______		
4.a. β	radians	______		
b. $R/_\beta$	radians	______		
5.a. θ	radians	______		
b. R_θ	radians	______		
6.a. ϕ	radians	______		
b. R_ϕ	radians	______		
7.a. E	Km	______		$\theta = 2\tan^{-1}(E/2H)$
b. R_E	Km	______		$R_\theta = 2\tan^{-1}(R_E/2H)$
8.a. N	Km	______		$\phi = 2\tan^{-1}(N/2H)$
b. R_N	Km	______		$R_\phi = 2\tan^{-1}(R_N/2H)$
9. H (Altitude)	Km	______		
C. Intensity Element				
1. S/N				
or 2.a. Dynamic				$S/N = \frac{\text{Dynamic Range}}{\text{Precision}}$
b. Precision				

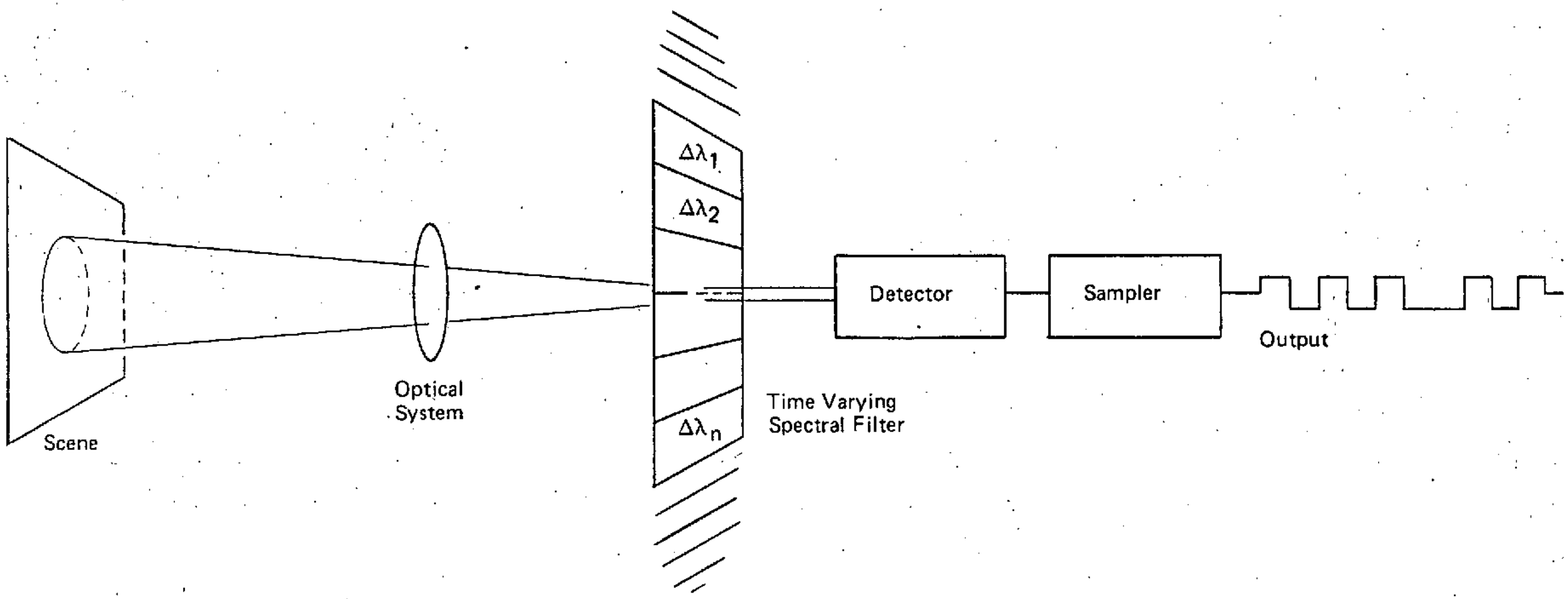


SINGLE DETECTOR SPECTROMETER - SIMULTANEOUS DISPLAY OF SPECTRUM

Passive Spectrometer
Single Detector
Simultaneous Display of λ

Instrument: ______________ Channel: ____________________

Input	Unit	Value	Other Required Inputs	Calculation Equations
A. Time Elements				
1. T_{so}	Seconds	_____	B,C	$\frac{\lambda}{2 R_\lambda T_{so}}$
2.a. T_{sc}	Seconds	_____	B,C	$\frac{\lambda}{2 R_\lambda T_{sc} \xi_s}$
b. ξ_s				
B. Spectral Elements				
1. λ (spectral coverage)	Å	_____		
2. R_λ (spectral resolution)	Å	_____		
C. Intensity Elements				
1. S/N		_____		S/N = $\frac{\text{Dynamic Range}}{\text{Precision}}$
or				
2.a. Dynamic Range		_____		
b. Precision		_____		

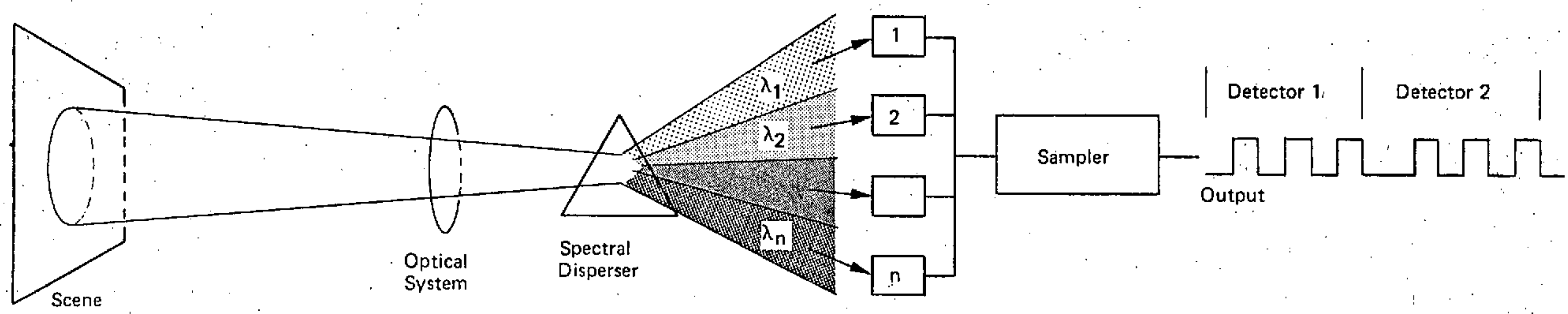


SPECTROMETER — SEQUENTIAL DISPLAY OF SPECTRUM

Passive Spectrometer
Single Detector
Sequential Display of λ

Instrument:__________ Channel:__________

Input	Unit	Value	Other Required Inputs	Calculation Equations
A. Time Element				
1. T_{so}	Seconds	____	B,C	$B = \frac{\lambda/R_\lambda}{2T_{so}}$
2.a. T_{sc}	Seconds	____	B,C	$B = \frac{\lambda/R_\lambda}{2T_{sc}\xi_s}$
b. ξ_s (scan efficiency)		____		
B. Spectral Element				
1. a. λ (spectral coverage)	$\mathring{A}$	____		
b. R_λ (spectral resolution)	$\mathring{A}$	____		
or 2. n (number of spectral bands)		____		$n = \lambda/R_\lambda$
C. Intensity Element				$S/N = \frac{\text{Dynamic Range}}{\text{Precision}}$
1. S/N		____		
or 2.a. Dynamic Range		____		
b. Precision		____		

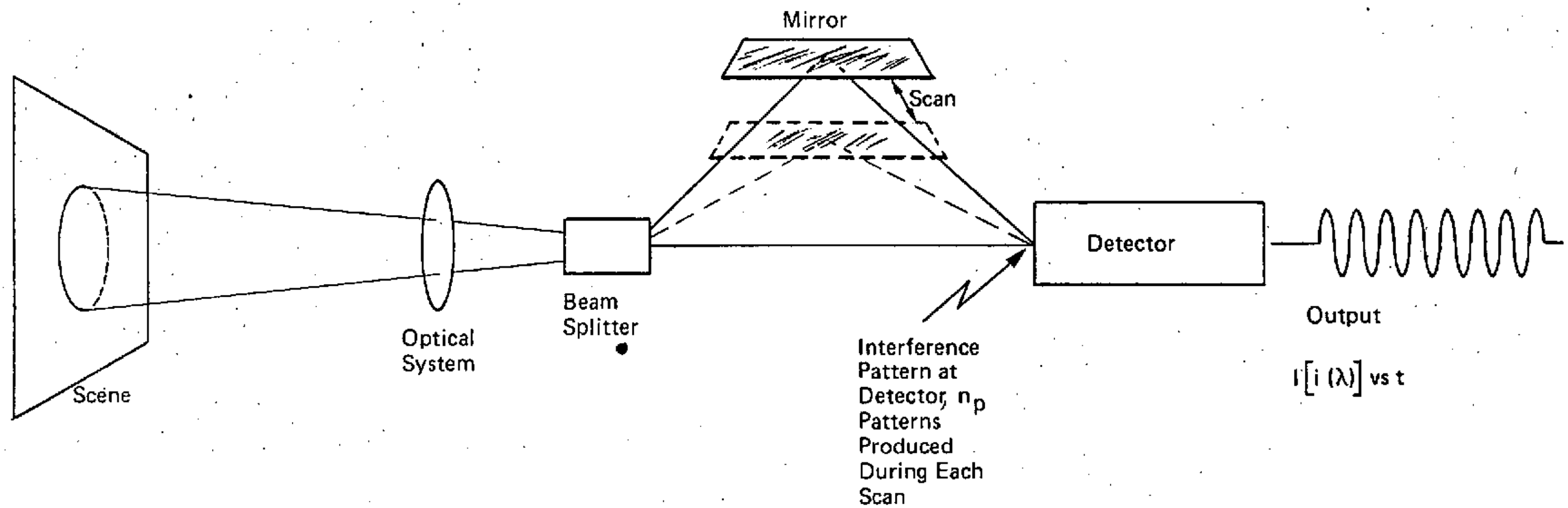


MULTIPLE DETECTOR SPECTROMETER

Passive
Spectrometer
Multiple Detectors

Instrument:______________ Channel:__________________

Input	Unit	Value	Other Required Inputs	Calculation Equations
A. Time Element			B,C	
1. T_F	Seconds	_____		$C = \frac{n_d \log_2(S/N)}{T_F}$ BPS
B. Array Size				
1. n (number of detectors)		_____		
C. Intensity Element				
1. S/N		_____		
or				
2. a. Dynamic Range		_____		$S/N = \frac{\text{Dynamic Range}}{\text{Precision}}$
b. Precision		_____		
or				
3. G (number of levels)		_____		$S/N = G$



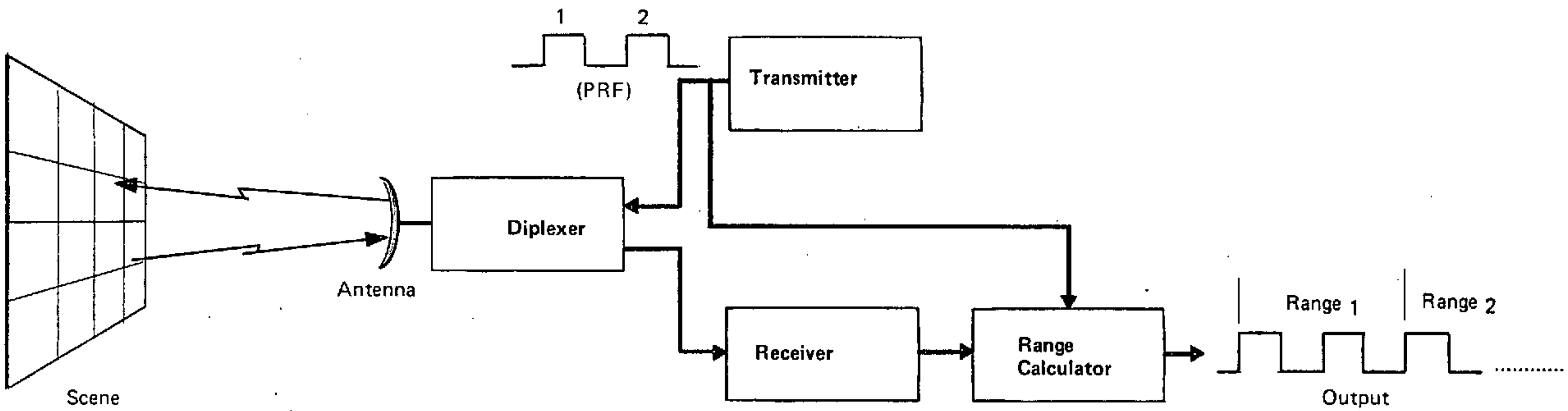
INTERFEROMETER

Analytical Sensor

Interferometer

Instrument: ________________ Channel: ________________

Input	Unit	Value	Other Required Inputs	Calculation Equations
A. Time Element				
1. T_{SO} (time to scan target)	seconds	______	B, C	$B = \frac{n_p}{2T_{SO}}$ Hz
or 2 a. T_{SC} (time for one complete scan)	seconds	______	B, C	$B = \frac{n_p}{2T_{SC}\,\xi_s}$ Hz
b. ξ_s				
B. Pattern Element		______		
1. n_p (number of patterns produced during each scan)				
C. Intensity Element				
1. Detector S/N		______		$C = 2B \log_2 (S/N)$ BPS
or 2 a. Detector Dynamic Range		______		$= \frac{n_p \log_2 (S/N)}{T_{SO}}$ BPS
b. Precision		______		$S/N = \frac{\text{Detector Dynamic Range}}{\text{Precision}}$



ACTIVE SENSOR - RANGING

Active Sensor

Ranging (Pulse)

Instrument: ______________________ Channel: ____________

Input	Unit	Value	Other Required Inputs	Calculation Equation
A. Time Element				
1. PRF (Pulse Repetition frequency)	sec^{-1}	______	B	$C = PRF \log_2 (L/R_L)$ bits/second
B. Data Element				
1 a. L (Range variation)	meters	______		
b. R_L (Precision)	meters	______		

ACTIVE SENSOR
ILLUMINATOR

Illuminators can operate in manners equivalent to radiometers, spectrometers, or cameras. For the purposes of this handbook, computing approximate bandwidth and data rates, the forms for the equivalent passive sensor are applicable. Thus to compute the approximate bandwidth/data rate, determine the characteristics of the scene and of the instrument operation that are of interest, and use the form for that type of passive instrument. For example, if the received radiation is reported as intensity as a function of wavelength, one of the forms for a spectrometer should be used.

V. DIGITAL DATA RATES FROM ANALOG SIGNALS

DIGITAL DATA RATES FROM ANALOG SIGNALS

Analog signals may be converted to digital signals, with theoretically no loss of information, by sampling at a rate greater than or equal to twice the highest frequency in the analog signal. The highest frequency is often expressed as, and is equivalent to, the bandwidth B.

The signal-to-noise ratio of the analog signal determines the number of bits required to accurately report the value of each sample, if the quantization noise is to equal the thermal noise. As Schwartz* explains, it

> The factor, G, the number of distinguishable amplitude levels, can be related to the signal-to-noise ratio of a system. For signal amplitude changes can be distinguished only if they are at least comparable to the rms noise level. If we arbitrarily assume, then, that a signal voltage change is distinguishable if it is equal to the rms noise voltage N, and assume a maximum signal voltage of S_v volts, there will be S_v/N_v distinguishable signal levels. Including 0 volts as an additional possible signal level,
>
> $$G = 1 + \frac{S_V}{N_V} \qquad (1)$$
>
> where S_ν/N_ν is the voltage signal-to-noise ratio

*Information Transmission, Modulation and Noise

Thus, assuming sampling at the minimum rate which will give theoretically no loss of information, and quantizing each sample to one of G amplitude levels, the digital bit rate is given by

$$C = 2B \log_2 G = 2B \log_2 (1 + S/N) \text{ bits per sec} \tag{2}$$

(see Figure 5.1)

In practice sampling may be done more often due to operational considerations. In this case the data rate is increased, although no more knowledge about the analog signal is imported. The data rate, when related to a sampling rate of P samples per second, is

$$C = P \log_2 G \tag{3}$$

Note: Equation (3) is identical to Equation (2) when $P = 2B$ and $G = 1+S/N$.

To illustrate the use of the above equations, the Scanning Radiometer on ITOS-1 will be investigated. It was shown in Section III that the bandwidth for the IR channel was 575 Hz and its dynamic range and precision were 180°-330°K and 1°K respectively. Since there are 150 1°K steps between 180° and 330°K, G from equation (1) is 150. From equation 2, the digital bit rate for this channel is

$$C = 2(575) \log_2 (150) = 8360 \text{ bits per second}$$

For the visible channel, $S/N = 200$ and thus

$$C = 2(575) \log_2 (201) = 8960 \text{ bits per second}$$

The overall bit rate is the sum of the bit rates of the two channels or 17, 320 bits per second.

This is the minimum required bit rate. If, for example, each channel is sampled at P=2,000 samples per second, the digital data rate would be, for the 1a channel

$$C = 2000 \log_2 (150) = 14{,}450 \text{ bits per second}$$

and for the visible channel

$$C = 2000 \log_2 (201) = 15{,}540 \text{ bits per second}$$

The overall bit rate in this case is 30,080 bits per second.

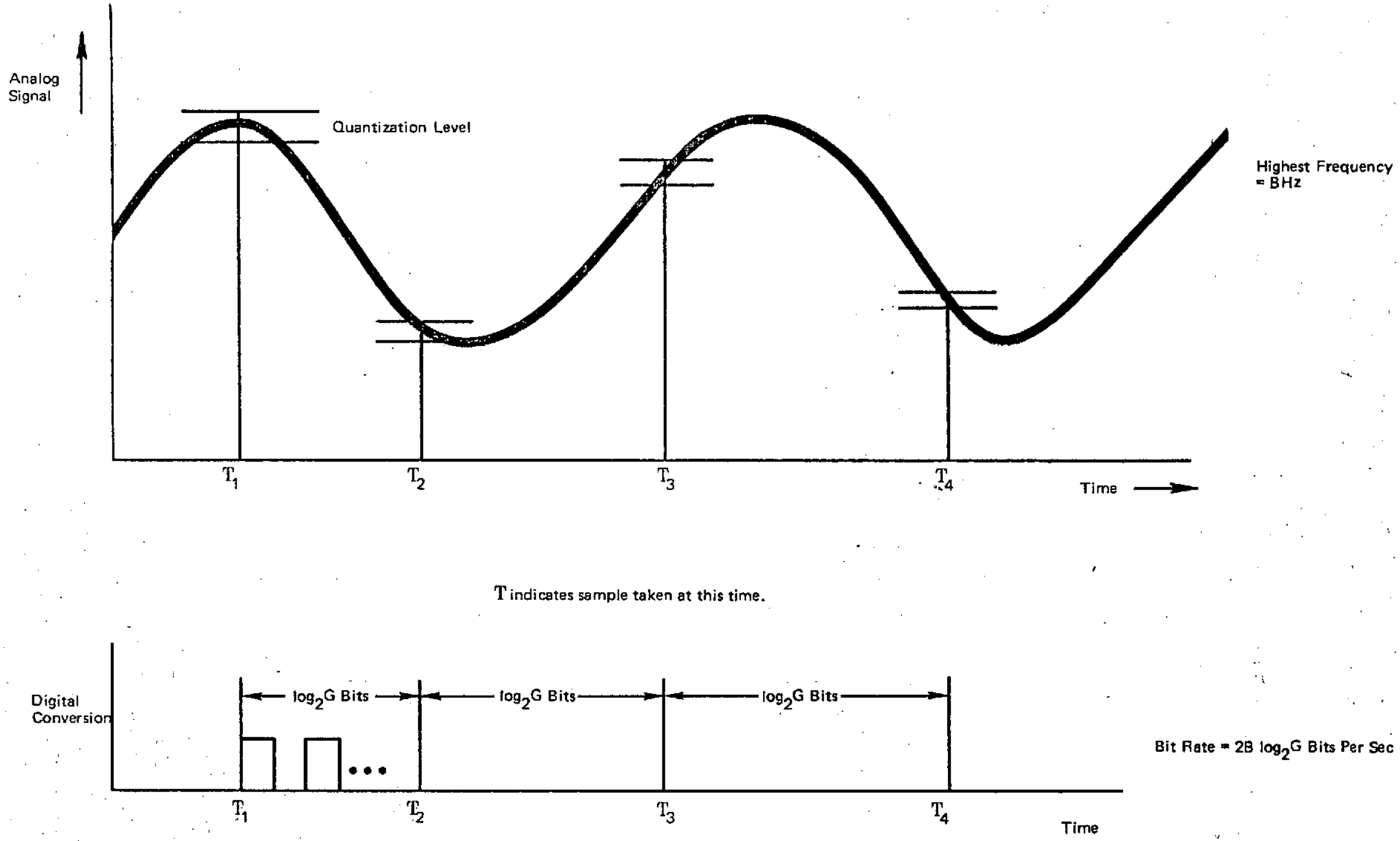


FIGURE 5.1. DIGITIZING AN ANALOG SIGNAL